SMAP Science Data Products and Algorithm Development

Eni Njoku[1], Peggy O'Neill[2], Dara Entekhabi[3], Jakob van Zyl[1], J. C. Shi[4], Randy Koster[2], Kyle McDonald[1], John Kimball[5], Wade Crow[6], Steven Chan[1]

(1) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA; (2) NASA Goddard Space Flight Center, Greenbelt, MD, USA; (3) Massachusetts Institute of Technology, Cambridge, MA, USA; (4) University of California, Santa Barbara, CA, USA; (5) Flathead Lake Biological Station, University of Montana, Polson, MT, USA; (6) USDA Agricultural Research Service, Beltsville, MD, USA

SMAP Science Requirements

SMAP **Hydrometeorology** requirements are driven by scales at which the surface and atmosphere interact through surface fluxes and the planetary boundary layer; scales of NWP models in the time horizon of SMAP; and scales of hydrologic forecast models for rivers and flash flood phenomena

The **Hydroclimatology** requirements are driven by data requirements of climate models used for seasonal prediction and global change studies. In the SMAP era these models are anticipated to run at 0.5 to 1 degree resolution.

The **Freeze/Thaw State** requirements are determined primarily by the scales of landscape heterogeneity in boreal regions.

Decadal Survey Objective	Application	Science Product Requirement
Weather Forecast	Initialization of numerical weather prediction (NWP)	Hydrometeorology
Climate Prediction	Boundary and initial conditions for seasonal climate prediction models	Hydroclimatology
	Testing land surface models in general circulation models	
Drought and Agriculture Monitoring	Seasonal precipitation prediction	Hydroclimatology
	Regional drought monitoring	
	Crop outlook	
Flood Forecast	River forecast model initialization	Hydrometeorology
	Flash flood guidance (FFG)	
	NWP initialization for precipitation forecast	
Human Health	Seasonal Heat Stress Outlook	Hydroclimatology
	Near-Term Air Temperature and Heat Stress Forecast	Hydrometeorology
	Disease Vector Seasonal Outlook	Hydroclimatology
	Disease Vector Near-Term Forecast (NWP)	Hydrometeorology
Boreal Carbon Source/Sink	Growing season length; Constraints on GPP and ecosystem respiration	Carbon Cycle

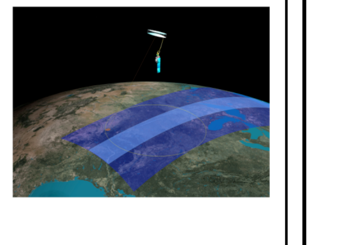
Requirement	Hydro-Meteorology	Hydro-Climatology	Carbon Cycle	Baseline Mission		Minimum Mission	
				Soil Moisture	Freeze/Thaw	Soil Moisture	Freeze/Thaw
Resolution	4-15 km	50-100 km	1-10 km	10 km	3 km	10 km	10 km
Refresh Rate	2-3 days	3-4 days	2-3 days[(1)]	3 days	2 days[(1)]	3 days	3 days[(1)]
Accuracy	4-6%(**)	4-6%(**)	80-70%(*)	4%(**)	80%(*)	6%(**)	70%(*)

(*) % classification accuracy (binary F/T)
(**) % volumetric water content, 1-sigma
[(1)]North of 45°N latitude

Baseline Mission Duration Requirement is 3 Years, Minimum is two years

Measurement Approach

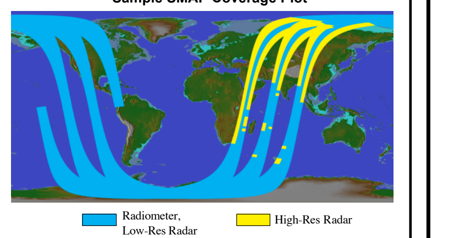
The SMAP instrument suite includes a radiometer and a synthetic aperture radar operating in the L-band range (1.20-1.41 GHz), providing coincident measurements of soil emission and backscatter with a capability to sense the top 5 cm of soil through moderate vegetation cover. The measurements will be analyzed to yield estimates of soil moisture and freeze/thaw state.



The SMAP antenna provides footprint sizes of 40 km for the radiometer and 30 km for the radar. The radar resolution can be enhanced to 300 to 700 meters by using unfocused synthetic aperture radar (SAR) processing using range and Doppler discrimination. Due to squint angle effects the achevable resolution varies across the swath. Resolution in the 1-3 km range ('hi-res') is achieved over the two outer 350-km-wide swath segments.

The radiometer operates continuously. The radar operates in two modes: The 'hi-res' mode for generating high resolution geophysical products, and a low-resolution ('lo-res') or real-aperture mode. To reduce the power consumption, data rate, and data volume, both radar modes operate only over the forward arc of the conical scan. To reduce the data rate and volume further, the high-resolution mode operates only over land and over the descending (am) portion of the spacecraft orbit.

Sample SMAP Coverage Plot



Retrieval Algorithms

A unique feature of SMAP is its ability to obtain simultaneous active and passive (radar and radiometer) measurements of the surface, with resulting improvements in spatial resolution and accuracy of the derived soil moisture and freeze/thaw products. The key derived geophysical products are soil moisture at 10 km resolution and freeze/thaw state at 3 km resolution.

- **Radiometer** - More accurate (less influenced by roughness and vegetation) but coarser resolution (40 km)
- **Radar** - High spatial resolution (1-3 km) but more sensitive to roughness and vegetation
- **Combined radar/radiometer** - generates optimal blend of resolution and accuracy

Soil Moisture

Soil moisture retrievals are based on microwave emission and backscatter models of vegetated surfaces. Emission (brightness temperature) can be represented by a layered single-scattering model of the form:

$$T_{Bp} = T_s e_p L_p + T_c (1 - \omega_p) [1 - L_p] [1 + r_p L_p]$$

$$L_p = \exp(-\tau_o/\cos\theta)$$

where, $p = v$ or h polarization, T_s is the soil temperature, T_c is the vegetation temperature, τ_o is the nadir vegetation opacity, ω is the vegetation single scattering albedo, and r_p is the soil reflectivity, related to the emissivity by $e_p = (1 - r_p)$. The vegetation opacity depends on the columnar vegetation water content, and the soil emissivity depends on both soil moisture and surface roughness. Retrieval of soil moisture thus requires corrections for effects of soil and vegetation temperature, vegetation water content, and surface roughness. Additional retrieval uncertainties arise from effects of soil texture, surface topography, and within pixel heterogeneity (water bodies, mixed vegetation, urban areas, etc.).

Radar backscatter for a vegetation-covered soil can be represented by:

$$\sigma^t_{pq} = \sigma^s_{pq} \; L^2_{pq} + \sigma^v_{pq} + \sigma^{sv}_{pq}$$

where, subscripts p, q refer to polarizations v or h, σ^s represents the soil surface contribution, σ^v represents vegetation volume scattering, σ^{sv} represents the scattering interaction between the soil and vegetation, and $L_{pq}{}^2$ is the two-way vegetation attenuation. The radar backscatter is influenced by surface roughness and vegetation to a higher degree than radiometric emission, but is not influenced by surface temperature.

Soil moisture retrieval algorithms are derived from an extensive heritage of field experiment data including:

– MacHydro'90, Monsoon'91, Washita'92, FIFE, HAPEX, SGP'97,'99, SMEX'02-'05, CLASIC'07, SMAPVEX'08.

Radiometer

Three radiometer retrieval approaches have been evaluated to date, with varying requirements for ancillary data:

- **Single-Channel:** uses H-polarized brightness temperature, corrected sequentially for surface temperature, vegetation water content, and surface roughness.
- **Reflectivity Ratio**: uses a derived ratio of vertical to horizontal reflectivity (insensitive to vegetation and roughness).
- **Iterative**: adjusts soil moisture and vegetation water content iteratively to minimize the difference between computed and observed V- and H-polarized brightness temperatures.

Radar

Two radar retrieval approaches are currently under consideration.

- **Snapshot algorithm:** will be used to produce the best estimate of soil moisture conditions at a given time instant using the multi-polarization data.
- **Time-Series Algorithm:** will use the temporal change in a single-channel radar cross-section to provide an improved estimate of the soil moisture change under more highly vegetated conditions.

In both cases, the data will first be classified into different vegetation levels so that the appropriate algorithms may be applied.

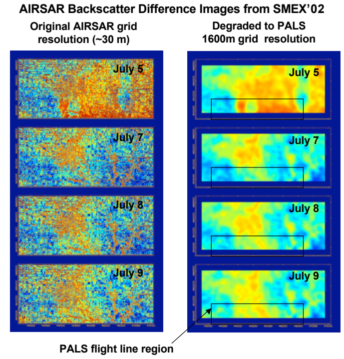
Radar-Radiometer

The radar-radiometer retrieval combines the 'hi-res' radar and 'lo-res' radiometer data to derive an optimal estimate of the soil moisture at intermediate resolution (nominally 10 km). There are a number of candidate algorithms under consideration for this approach, including both snapshot and time-series versions.

Observations from the SMEX'02 field campaign illustrate the potential of these approaches. In this experiment, data from the AIRSAR and PALS airborne instruments were acquired over mixed agricultural sites in the Walnut Creek watershed, Iowa, over a 10-day period. Scattered rain occurred over different areas of the watershed on the evenings of July 4, 5, 6, and on July 10.

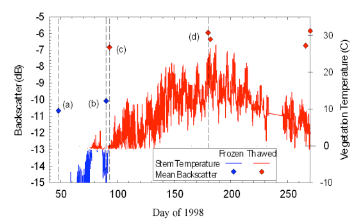
AIRSAR backscatter difference images below - displaying differences each day from dry conditions on July 1 (when the region had remained dry for several weeks) - show changes in backscatter responses ($\Delta\sigma_o$) primarily due to changes in soil moisture. The spatial and temporal patterns of wetting and drying are preserved even after degrading the resolution of the difference images from 30 m to 1600 m, indicating linearity of the backscatter response over this range of conditions.

AIRSAR Backscatter Difference Images from SMEX'02



Freeze/Thaw

Temporal change detection algorithms are used to classify and map the landscape freeze/thaw (F/T) state using SMAP time-series L-band radar data. The F/T algorithms include a seasonal threshold approach representing a baseline algorithm, as well as optional moving window and temporal edge detection algorithms that may eventually augment the current baseline algorithm. These algorithms require only time-series radar backscatter observations to derive landscape F/T state information. However, ancillary data can be used to enhance the algorithm performance, including the use of digital terrain, land cover and open water classification maps to refine algorithm parameters and mask open water and permanent ice areas during operational processing.



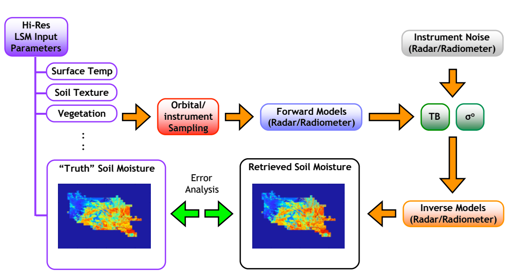
JERS L-band backscatter data from central Alaska show the spring thaw transition. The SMAP global mapping capability and high revisit will provide a 15- to 20-fold improvement in temporal discrimination of freeze/thaw state transitions across boreal latitudes.

Seasonal threshold approaches examine the time series progression of the remote sensing signature relative to signatures acquired during a seasonal reference state or states. These techniques are well-suited for application to data with temporally sparse or variable repeat-visit observation intervals and have been applied to ERS and JERS Synthetic Aperture Radar (SAR) imagery.

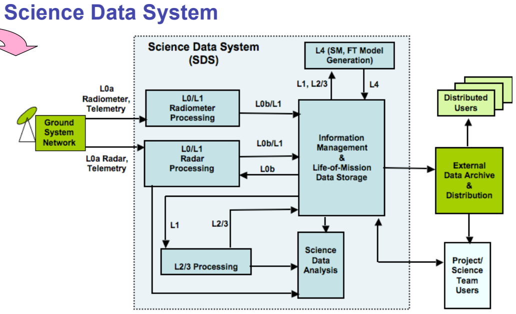
Algorithm Testbed

The SMAP Algorithm Testbed is currently under development and will be used to:

- Evaluate the relative merits of different microwave models, retrieval algorithms, and ancillary data for meeting SMAP's soil moisture and freeze/thaw science objectives, based on a common set of input and processing conditions.
- Provide a system that can be used to test the integrated suite of SMAP science product algorithms as a prototype for the SMAP Science Data System (SDS).
- The Testbed is based on the Observing System Simulation Experiment (OSSE) developed during the Hydros Risk-Reduction Phase.



Science Data System



International Workshop on Microwave Remote Sensing for Land Hydrology: Research and Applications, Oxnard, California, USA, October 20-22, 2008

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration